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# How to probe the spin–dependent gluon distributions †

T. Morii[1,2], S. Tanaka[1] and T. Yamanishi[2]

Faculty of Human Development, Division of Sciences for Natural Environment,
Kobe University, Nada, Kobe 657, Japan[1]
Graduate School of Science and Technology, Kobe University, Nada, Kobe 657, Japan[2]



**Abstract**

Two–spin asymmetries $A_{LL}^{\pi^0}$ are calculated for various types of spin–dependent gluon distributions. It is concluded that the E581/704 data on $A_{LL}^{\pi^0}$ do not necessarily rule out the large gluon polarization but restrict severely the $x$ dependence of its distribution. Moreover, $A_{LL}^{J/\psi}$ are calculated for the forthcoming test of spin–dependent gluon distributions.

The advent of *so–called* "the proton spin crisis" which has emerged from the measurement of $g_1^p(x)$ by the EMC Collaboration, has stimulated a great theoretical and experimental activity in paricle physics [1]. So far various theoretical approaches have been provided to get rid of the crisis [2]. Although some of them are very successful, a lot of problems remain to be solved. One of the remaining problems is on the polarized gluon distributions ($\delta G(x)$) in a proton. In this Talk, we are concentrated on several physical processes such as inclusive $\pi^0$– [3], high $p_T$ direct photon– [4] and inclusive J/$\psi$–productions [5] in polarized hadron–polarized hadron reactions, which possess important informations on the polarized gluons. Here we discuss only $\pi^0$– and J/$\psi$–productions. The interesting physical parameter to be discussed is the two–spin

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asymmetry $A_{LL}$ as a function of transverse momenta $p_T$ of produced particles like $\pi^0$, $\gamma$ and J/$\psi$. $A_{LL}$ is defined as

$$
\begin{aligned}
A_{LL} &= \frac{[d\sigma_{\uparrow\uparrow} - d\sigma_{\uparrow\downarrow} + d\sigma_{\downarrow\downarrow} - d\sigma_{\downarrow\uparrow}]}{[d\sigma_{\uparrow\uparrow} + d\sigma_{\uparrow\downarrow} + d\sigma_{\downarrow\downarrow} + d\sigma_{\downarrow\uparrow}]} \\
&= \frac{Ed\Delta\sigma/d^3p}{Ed\sigma/d^3p} \ ,
\end{aligned}
\tag{1}
$$

where $d\sigma_{\uparrow\downarrow}$, for instance, denotes that the helicity of a beam particle is positive and that of a target particle is negative.

In order to investigate how these processes are affected by spin–dependent gluon distributions, we take the following types of $x\delta G(x)$ :

(a) our model [6] ;

$$
\begin{aligned}
&x\delta G(x, Q^2 = 10.7\mathrm{GeV}^2) = 3.1x^{0.1}(1-x)^{17} \ \text{then} \\
&\Delta G(Q^2_{EMC}) = 6.32 \ .
\end{aligned}
\tag{2}
$$

(b) Cheng–Lai type model [7] ;

$$
\begin{aligned}
&x\delta G(x, Q^2 = 10\mathrm{GeV}^2) = 3.34x^{0.31}(1-x)^{5.06}(1-0.177x) \ \text{then} \\
&\Delta G(Q^2_{EMC}) = 5.64 \ .
\end{aligned}
\tag{3}
$$

(c) BBS model [8] ;

$$
\begin{aligned}
&x\delta G(x, Q^2 = 4\mathrm{GeV}^2) = 0.281\left\{(1-x)^4 - (1-x)^6\right\} + 1.1739\left\{(1-x)^5 - (1-x)^7\right\} \\
&\text{then} \quad \Delta G(Q^2_{EMC}) = 0.53 \ .
\end{aligned}
\tag{4}
$$

(d) no gluon polarization model [7] ;

$$
x\delta G(x, Q^2 = 10\mathrm{GeV}^2) = 0 \ \ \text{then} \ \ \Delta G(Q^2_{EMC}) = 0 \ . \tag{5}
$$

Among these distributions, $\Delta G$ of types (a) and (b) are large while those of types (c) and (d) are small and zero, respectively. The $x$ dependence of these distributions are depicted in Fig.1, where $x\delta G(x, Q^2)$ of types (b), (c) and (d) are evolved up to $Q^2 = 10.7\mathrm{GeV}^2$ by the

Altarelli–Parisi equations. The $x\delta G$ which is taken up so far by most of people [9] has almost the same behavior as that of type (b) and has large $\Delta G$. As can be seen, the $x\delta G(x)$ of type (b) has a peak at $x \approx 0.05$ and gradually decreases with increasing $x$ while that of (a) has a sharp peak at $x < 0.01$ and rapidly decreases with $x$.

First, we discuss the inclusive $\pi^0$–production. So far, only this process has been measured by the E581/704 Collaboration at Fermilab[10] by using longitudinally polarized proton (antiproton) beams and longitudinally polarized proton targets. Using the spin–dependent gluon distribution functions ((a)$\sim$(d)) presented above, we have calculated $A_{LL}^{\pi^0}(pp)$ and $A_{LL}^{\pi^0}(\overline{p}p)$, which are shown in Figs.2 and 3 for $\sqrt{s} = 20$ GeV and $\theta = 90°$, respectively. Here we typically choose $Q^2 = 4p_T^2$ with the transverse momentum $p_T$ of $\pi^0$.

Comparing theoretical predictions with the experimental data, we see that not only the no gluon polarization model (type (d)) but also our model (type (a)) seem to be consistent with the experimental data for both $pp$ and $\overline{p}p$ collisions. It is remarkable to see that type (a) works well though it has large $\Delta G$. Owing to the kinematical constraint of $x$ in the hard–scattering parton model, the contributions from $0 < x < 0.05$ to $A_{LL}^{\pi^0}(\overset{(-)}{p}p)$ are vanishing. Accordingly, there are no significant contributions from the spin–dependent gluon distribution of type (a) to $A_{LL}^{\pi^0}$ though $\Delta G(Q^2)$ for this case is quite large. However, if we take the polarized gluon distribution $x\delta G(x)$ of type (b) which is still large for $x > 0.05$, we have a significant contribution from the large $x\delta G(x)$ to $A_{LL}^{\pi^0}$ and then the result becomes inconsistent with the E581/704 data. Furthermore, if the value of $x\delta G(x)$ is not very small for $x > 0.15$ even though $\Delta G(x)$ is small (as in the case of type (c)), the calculation does not agree with the experimental data. Therefore, one can conclude that a large gluon polarization inside a proton is not necessarily ruled out but the shape of the spin–dependent gluon distribution function is strongly constrained by the E581/704 data.

Next, in order to get a more direct information of spin–dependent gluon distributions, let us discuss the inclusive J/$\psi$ production process in polarized proton–polarized proton collisions [5]. Since the J/$\psi$ productions come out only via gluon–gluon fusion processes at the lowest order of QCD diagrams, this quantity is strongly sensitive to the spin–dependent gluon distribution in a proton. For estimation of $A_{LL}^{J/\psi}(pp)$, we take the spin–dependent gluon distributions (a), (b), (c) and (d) given by eqs.(2), (3), (4) and (5). Setting $\theta = 90°$ ($\theta$ is the production angle

of J/$\psi$ in the CMS of colliding protons) and using the spin–independent gluon distribution function of the DO parametrization [11] for (a), the DFLM [12] for (b) and (d) and the BBS [8] for (c), we have calculated $A_{LL}^{J/\psi}(pp)$ for some choices of $Q^2$ ; $Q^2 = m_{J/\psi}^2 + p_T^2$, $4p_T^2$, $(\hat{s}\hat{t}\hat{u})^{1/3}$, $-\hat{t}$ and so on. We see that $A_{LL}^{J/\psi}(pp)$ for each type of the spin–dependent gluon distributions is insensitive to the choice of $Q^2$. Thus, we here take $Q^2 = m_{J/\psi}^2 + p_T^2$ by taking the mass effect of the J/$\psi$ particle into account. The results of $A_{LL}^{J/\psi}(pp)$ are shown in Fig.4 as a function of $p_T$ of the J/$\psi$ at (A) $\sqrt{s} = 20$ and (B) 100 GeV. At $\sqrt{s} = 20$ GeV our largely polarized gluon distribution, (a), contributes little to $A_{LL}^{J/\psi}(pp)$ in all $p_T$ regions because the kinematical region near the peak of $x\delta G(x)$ is truncated. The $A_{LL}^{J/\psi}$ predicted with type (a) is not so significantly different from that with no gluon polarization (type (d)), and hence we cannot practically find the difference between them. However, for higher energies such as $\sqrt{s} = 100$ GeV, we can distinguish types (a) from (d) for spin–dependent gluon distributions by choosing a moderate $p_T$ region. In addition, one can see that the behavior of $A_{LL}^{J/\psi}$ for types (b) and (c) largely differs from that for types (a) and (d) at $\sqrt{s} = 20$ and 100 GeV. Therefore, it is expected that one can either rule out or confirm types (b) and (c) by measuring $A_{LL}^{J/\psi}$ particularly in rather large $p_T$ regions.

In summary, we have studied the effect of the polarized gluon distributions on the two–spin asymmetry $A_{LL}^{\pi^0}$ and $A_{LL}^{J/\psi}$ in the polarized proton (antiproton)–polarized proton collisions. We have concluded that although the E581/704 data of $A_{LL}^{\pi^0}$ are very useful to examine the behavior of polarized gluon distributions, they are not enough to distinguish type (a) from type (d). To get more deep understandings of polarized gluons in a proton, we have to analyze other reactions such as polarized $\ell$p collisions, which are now under investigation.

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## Figure captions

**Fig. 1:** The $x$ dependence of $x\delta G(x,Q^2)$ for various types (a)–(d) given by eqs.(2)– (5) at $Q^2 = 10.7$ GeV$^2$.

**Fig. 2:** Two–spin asymmetry $A_{LL}^{\pi^0}(pp)$ for $\sqrt{s} = 20$ GeV and $\theta = 90°$, calculated with various types of $x\delta G(x)$, as a function of transverse momenta $p_T$ of $\pi^0$. The solid, dashed, small–dashed and dash–dotted lines indicate the results using types (a), (b), (c) and (d) in eqs.(2), (3), (4) and (5), respectively. Experimental data are taken from [10].

**Fig. 3:** Two–spin asymmetry $A_{LL}^{\pi^0}(\overline{p}p)$ for $\sqrt{s} = 20$ GeV and $\theta = 90°$, calculated with types (a)–(d) for $x\delta G(x)$, as a function of transverse momenta $p_T$ of $\pi^0$. Data are taken from [10].

**Fig. 4:** Two–spin asymmetries $A_{LL}^{J/\psi}(pp)$ for $\theta = 90°$ calculated with types (a)–(d) for $x\delta G$, as a function of transverse momenta $p_T$ of J/$\psi$ at (A) $\sqrt{s} = 20$ GeV, and (B) $\sqrt{s} = 100$ GeV. The solid, dashed, small–dashed and dash–dotted curves correspond to types (a), (b), (c) and (d), respectively. $Q^2$ is typically taken to be $m_{J/\psi}^2 + p_T^2$.